Display resolution enhancement with optical scanners

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We have developed a novel, low-cost, and effective technique for display resolution and fill-factor enhancement. By using optical scanners with fast nematic liquid-crystal polarization switches and birefringent materials, we have increased the perceived pixel count of a low-resolution display and also its display fill factor. The resulting display resolution was quadrupled by the optical scanners without increasing the display die sizes or input–output counts. The display optical system architecture, scanner design, packaging, and experimental results of the display system performance are discussed. © 2001 Optical Society of America

OCIS codes: 100.2980, 100.3010, 070.6020, 120.2040, 120.5800, 120.4640.

1. Introduction

Advances in wireless communication technology are bringing an increasing amount of information to portable products. Compact displays with high resolution are highly desired by business professionals who need instant access to fax, e-mail, the Internet, images, etc. As the display pixel count increases, the cost and the power consumption of the display system also increase. In addition, an increased count creates serious packaging issues because a large number of input–output contact pads have to be packed closely into a small area. For a one-fourth video graphics array (VGA) display with 240 × 320 pixels, a matrix-addressing scheme leads to one input–output for each column and row, resulting in a total of 560 input–output pads. When the display resolution is increased to VGA resolution (480 × 640 pixels), the chip size is quadrupled and 1120 interconnect leads are required. The quadrupled die size plus complex interconnection make the VGA display module fairly expensive.

An alternative approach is to use an optical scanning technique to increase display resolution.[1–4] This method does not require an increase in actual display pixels and thus is potentially low in cost. The approach uses time-division multiplexing to create many perceived pixels from one emitting area. This is accomplished by one optically moving the image of the pixel from its original position in space to different positions while simultaneously changing the image information emitted by the pixel. If this is done fast enough, the observer perceives multiple pixels in the image, even though they are created sequentially in time by the same emitting area and scanned through different locations. If the pixel is scanned between two different areas, the perceived pixel count of the display doubles.

Fast scanning speeds are necessary to create an integrated high-quality image without flickering. We have developed a very fast nematic liquid-crystal switch with a total rise and fall time of 1 ms to support the enhanced display resolution. Particularly, we have optimized scanner performance using the industry standard cell gap of 5 μm to achieve high manufacturing yield and low tooling cost.

We demonstrated the display resolution enhancement effect on the VirtuoVue (VirtuoVue is a registered trademark of Motorola, Inc.) display image array. Experimental results demonstrate that the illegible characters in low-resolution displays become easily recognizable when the display resolution is enhanced with optical scanners. In the following, we provide background information on display resolution enhancement by use of optical scanners and then discuss in detail liquid-crystal scanners, image displacers, control electronics, compact packaging, and display system characteristics with resolution enhancement effects.

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Received 4 April 2000; revised manuscript received 9 November 2000.

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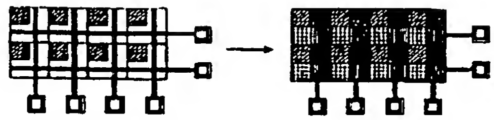


Fig. 1. Four pixels were formed from one original pixel by use of optical scanning, and the display fill factor was increased fourfold. The display resolution was quadrupled without increasing the display die size or number of interconnects.

2. Background

The human visual system has the capability of spatially and temporally integrating visual information. Spatial and temporal signals are perceived as continuous and steady images when the signal frequency is beyond the critical flicker fusion frequency.[5,6] An observer perceives no motion of the signals when the temporal frequency is higher than 60 Hz. When a pixel is moved to N different locations and the motion is completed within 1/60 s, we observe N stable pixels. Thus the perceived display resolution and image quality can be improved substantially for a small display by use of optical scanners.

The increase in the perceived display resolution depends on the layout of the display image sources. Overlap of adjacent scanned pixels should be avoided to produce good image quality. For the VirtuoVue display image array used, the pixel pitch was 20 μm with a 10 μm $\times$ 10 μm emitting region. This made it convenient to scan the pixel between four spots, as shown in Fig. 1, thus quadrupling the perceived pixel count. Image data were fed into the system four times as fast, producing a virtual image with four times the perceived pixels and four times the addressability.

Another critical parameter in the determination of image quality of a display is the display's fill factor. This quantity is defined as the ratio of the light-emitting area of a pixel to the total area of the pixel. As the fill factor is decreased, characters appear to be composed of dots rather than continuous lines; and as the fill factor is increased, characters look more continuous and well formed. In general, the higher the fill factor, the greater the image quality. The VirtuoVue display had a fill factor of only 25%. By using optical scanning to increase the display resolution, we simultaneously increased the display fill factor fourfold.

Various scanning methods have been considered for display resolution enhancement applications. Piezoelectric, electro-optic, and acousto-optic scanners all have a high driving voltage, which is not suitable for portable products. Galvanometric and holographic scanners and rotating polygons have mechanical moving parts and are large in size, which are not desirable in portable products. Deformable mirrors, micromachined gratings, and liquid-crystal phased-array scanners are compatible with integrated circuit technologies, but it is difficult to achieve large scanning apertures with these approaches. Their cost is also relatively high for portable products. We developed a nonpixelated liquid-crystal scanner for display resolution enhancement characterized by low power consumption, low drive voltage, compact size, low cost, and an absence of mechanical moving components.

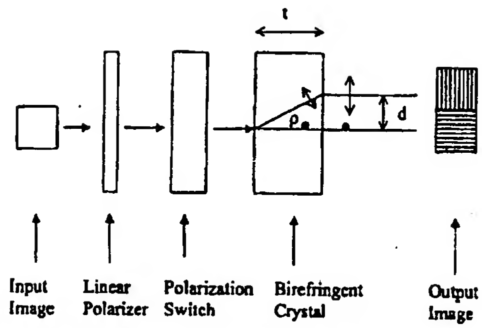


Fig. 2. Resolution of the output image that was doubled by use of one polarization switch and one piece of birefringent crystal when the polarization switch was synchronized with input image signals.

The liquid-crystal scanner consists of a liquid-crystal polarization switch and a thin film of birefringent crystal (see Fig. 2). The liquid-crystal polarization switch rotates the polarization direction of incoming linearly polarized light either 0° or 90°. If the image source is not linearly polarized already, a linear polarizer is placed between the image source and the liquid-crystal scanner. The birefringent film displaces the extraordinary ray, whereas the ordinary ray is not deflected. When the switch is biased so that half of the time the polarization is along the extraordinary direction and half of the time along the ordinary direction (and this switching is done fast enough for visual integration), double images, with the same intensity in each one, are observed. When the bias voltage is synchronized with input image data, and the data, are changed for each of the states, a different image is shown for each of the doubled images. The pixel count of the display is effectively doubled. With a second resolution doubler placed along the perpendicular direction, the display pixel count is quadrupled.

The resolution quadruplers that we built consist of one linear polarizer and two liquid-crystal scanners with optical axes orthogonal to each other (see Fig. 3). The image position is shifted by one changing the bias voltage on the polarization switches. Each polariza-

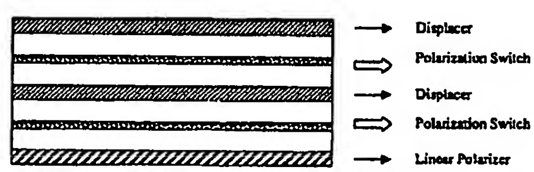


Fig. 3. Assembly of a liquid-crystal quadrupler. A resolution quadrupler consists of one polarizer, two polarization control switches, and two pieces of birefringent crystal.

tion switch has two states, and two polarization switches result in four image positions. When the four input images are synchronized with the bias voltages on the polarization switches, and all four images are presented within 1/60 s (16.6 ms), the viewer perceives a single integrated image with the combined information content of the four images. Thus display pixel count and addressability are effectively quadrupled.

3. Liquid-Crystal Polarization Switch

The liquid-crystal polarization switch is based on the electro-optic principle of a switchable half-wave plate. The switch is composed of a thin layer of liquid-crystal material sandwiched between two glass substrates. The liquid crystal is a uniaxial, birefringent medium with the optic axis parallel to the orientation of the liquid-crystal molecules. Transparent electrodes on each side of the liquid-crystal layer allow a drive voltage to be applied across the liquid-crystal layer. For the observer to perceive the integrated resolution-enhanced image, all four images must be shown within 16.6 ms. If the display of each image frame is sustained for 2 ms, the switching response of the polarization control switch must be less than 2.1 ms to ensure that no image flickering is observed.

Ferroelectric liquid-crystal (FLC) devices were first considered because of their fast speed. FLC polarization switches are bistable. The orientation of the switch's optic axis is controlled by the polarity of the voltage placed across the device electrodes. When a positive or negative voltage is applied to the electrodes, one of the two states can be selected. The FLC cell is oriented so that when -5 V are applied, the optic axis of the FLC layer is parallel to the polarization direction of the incident polarized light. When $+5$ V are applied, the optic axis of the FLC layer is oriented at roughly 45° with respect to the polarization direction of the incident polarized light. After passing through the FLC layer, the orientation of the polarization axis of the transmitted light was rotated about 90°. The thickness of FLC layer was optimized at 605 nm. The turn-on time was 80 μs for 10–90% and turn-off time was 80 μs for 90–10%. The power consumption was approximately 1 mW.

Test results initially showed high-quality images with enhanced resolution and a high contrast ratio. After four weeks, however, scattered background light was observed, especially along a particular direction. This is due to the degradation of the FLC cell. FLC molecules lost their alignment and thus caused light to be scattered randomly in various directions. Most molecules were still aligned along a certain direction, which caused strong scattering in that particular direction. Cross talk between the optically induced pixels was also observed. This was due to the light becoming elliptically polarized after traveling through the FLC cell. The other possibility was that the polarization direction of the linear polarized light was not rotated by 90°. If the linearly polarized light made an angle other than 0° or 90° to the intrinsic optic axes of the lithium niobate crystal, the light would be split into two branches after traveling through the film, with one branch deflected and the other one remaining undeflected.

Other disadvantages of FLC devices include a small cell gap and a narrow temperature operation range. The cell gap of the FLC device was approximately 2 μm, which is much less than the liquid-crystal industry standard of 5 μm. The normal operating temperature range was from 0 to 50 °C, which was not satisfactory for use in cold winters or hot summers. When pressure was applied to the FLC shutter, image degradation was observed.

Because nematic liquid-crystal devices are more resistant to mechanical and electrical shocks and have a much larger operating temperature range than FLC devices, most of the liquid-crystal displays available on the market are made of nematic liquid crystals. However, conventional twisted nematic (TN) liquid crystal and supertwisted nematic liquid-crystal devices have fairly slow response times. We developed a high-speed nematic liquid-crystal shutter using surface-mode devices.[7,8] In surface-mode devices, the bias voltage changes only the director direction of molecules along the surface, whereas the director direction in the center is roughly unchanged. In a regular TN cell, the liquid-crystal molecules are completely twisted or untwisted when a bias voltage is applied. Thus the switching speed for a surface-mode device is much faster than that of a conventional TN device.

The nematic liquid-crystal polarization switch was made of 0.7-mm glass with a cell gap of 5 μm. The switching speed of the nematic liquid-crystal device is inversely proportional to the square of its cell gap. Even though a faster switch could be achieved with a smaller cell gap, a cell gap of 5 μm was chosen for high manufacturing yield. The total thickness of the switch was 1.5 mm. The switch was fairly small with a clear aperture of 4 mm × 6 mm and overall dimensions of 10 mm × 10 mm. The switch was biased with an ac square wave or sine wave for the on state and zero voltage for the off state. The measurement results on response time, transmission, and contrast are described in the following paragraphs.

Response time was defined as the total optical rise and fall time from 10 to 90% of the final values. Response time of a nematic liquid-crystal shutter is a function of cell gap, viscosity, temperature, and bias voltage. Generally, when temperature increases, viscosity decreases. Response time is thus decreased. Figure 4 illustrates the response time as a function of temperature for the liquid-crystal switches. The total switching on and off time was only 0.8 ms at room temperature. The device switched at 0.3 ms for both on and off operation, which resulted in a very fast response time of 0.6 ms at 60 °C. At low temperatures, the switch was substantially slower than it was at room temperature. The response time was approximately 11.6 ms at -20 °C.

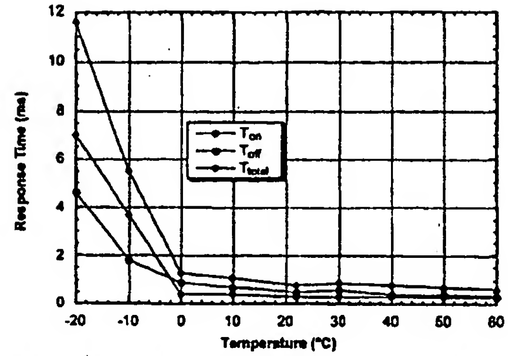


Fig. 4. Measured response time as a function of temperature for the polarization switch.

The measured transmission efficiency through a polarization switch without a linear polarizer was 92%. If the emitted light from the display is unpolarized, light would have to pass through a linear polarizer first because the device switches only linearly polarized light. The measured transmission efficiency through one polarizer was 42%. The measured transmission efficiency through a polarization switch with one polarizer was 38%. Total measured transmission efficiency of the quadrupler with one polarizer, two pieces of birefringent crystal, and two polarization switches was 35.4%. The above transmission was measured when the switch was biased with a ±10-V ac square wave. The transmission efficiency was 1.5% lower when the switch had no bias voltage. This indicated that there was greater scattering loss by liquid-crystal molecules when the switch was unbiased.

The contrast of the liquid-crystal polarization switch was defined as the intensity ratio between the two perpendicular polarization directions that corresponded to the directions of maximum and minimum intensity. It was a strong function of bias voltage. We defined the intensity ratio as contrast because it indicated the amount of pixel cross-talk and intensity variation between adjacent pixels for a resolution-enhanced image. Figure 5 shows the contrast versus bias voltage at various temperatures. When no voltage was applied, the contrast was approximately 5. The intensity along the two polarization directions was approximately equal when the switch was biased at ±2.5 V. The contrast increased as the bias voltage increased.

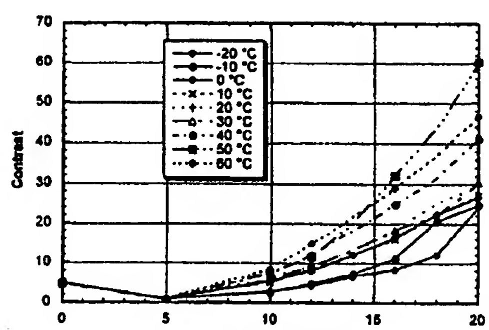


Fig. 5. Measured contrast as a function of bias voltage and temperature for the polarization switch. pk–pk, peak to peak.

The contrast ratio was excellent when the liquid-crystal switch was biased at ±10 V. The contrast ratio was better than 20 across the whole temperature range of −20 to 60 °C when the switch was biased at ±10 V. The contrast at room temperature was approximately 30, which indicated that the pixel cross-talk and intensity variation between adjacent pixels was less than 3.3%.

4. Image Displacer

The two pieces of special-cut birefringent crystal are called image displacers because they displace the extraordinary ray while keeping it parallel to the ordinary ray. The displacement of the extraordinary ray is determined by the thickness of the film and how the crystal is cut relative to the intrinsic axes of the birefringent crystal. The displacement distance d after traveling through a plate of thickness t is given by

$$d = t\tan(\rho), \tag{1}$$

where ρ is the walk-off angle that is defined as the angle between the ordinary and the extraordinary rays in the birefringent crystal (see Fig. 2).

The ordinary ray does not walk off at all. The extraordinary ray walk-off angle ρ is the difference between the direction of k (ordinary ray traveling direction) and Pointing vector $\mathbf{S}$ (extraordinary ray traveling direction), which is the same as that between $\mathbf{D}$ (the displacement vector) and $\mathbf{E}$ (the electromagnetic field vector) and is given by

$$\rho = \arctan\left(\tan\theta\,\frac{n_o^2}{n_e^2}\right), \tag{2}$$

where θ is the polar angle between the optical axis and the propagation direction and n_o and n_e are the optical indexes along the ordinary and extraordinary axes. When $n_o - n_e \ll n_o$, the maximum value of ρ is achieved when θ is approximately 45°.

Birefringent crystals such as tourmaline, calcite, quartz, sodium nitrate, and rutile can all be used as the image displacer material. Lithium niobate was chosen because it is one of the most versatile and well-developed active optical materials. Because the pixels have a 20-μm pitch with 10-μm emitting areas, the pixels generated by the optical scanner would be displaced by 10 μm from the original pixel position.

To cut lithium niobate material at exactly 45° is fairly expensive. There is not much gain in one choosing the exact value of θ at 45° to maximize ρ. A low-cost approach was to use double-sided polished surface acoustic-wave wafers with a 38° cut. From

Eq. (2), the walk-off angle for a wavelength of 605 nm was calculated to be 2.04° at room temperature. From Eq. (1), the thickness required for a 10-μm image displacement was calculated to be 273 μm by use of a lithium niobate crystal with a 38° cut.

The specifications for the lithium niobate crystals used in the resolution quadrupler are as follows:

1. 128-deg Y cut.
2. Size: 5 mm × 7 mm × 273 μm.
3. Width and length tolerance: ±0.1 mm.
4. Thickness tolerance: <13 μm.
5. Flatness: <λ/4 at 605 nm.
6. Surface quality: scratch and dig <20/10.
7. Transmission: >90%.
8. Uncoated.

5. Assembly of the Resolution Quadrupler

The resolution quadrupler consists of one linear polarizer, two polarization control switches, and two pieces of birefringent crystal (see Fig. 3). The polarization control switch was designed so that the two perpendicular polarization directions were along the x and the y directions. The two polarization control switches were made identical for ease of manufacturing. The two pieces of birefringent crystal were cut so that one piece displaced the extraordinary ray along the x direction and the other piece displaced the extraordinary ray along the y direction.

The linear polarizer was laminated onto the bottom glass substrate of the bottom polarization control switch. The bottom image displacer was then placed on top of the bottom polarization control switch. The image displacer had to be aligned fairly well with the polarization control switch; otherwise, the contrast of the resolution-enhanced image would be decreased. The alignment tolerance was approximately ±2°. The bottom image displacer and polarization control switch were assembled permanently with UV epoxy. The alignment was achieved by use of test patterns of straight lines along row and column directions. We adjusted the alignment by observing the position of the displaced image relative to the original image. Then the second polarization switch was placed on top of the bottom image displacer, and the second image displacer was placed on top of the second polarization switch. All components were aligned carefully relative to each other and assembled with UV epoxy.

Four electrical contacts were required for the two polarization control switches. Because it was difficult to solder wire directly onto the indium tin oxide (ITO) surface, a compact module was designed so that an electrically conductive spring could be pressed directly onto the ITO. The bottom substrate size of the polarization switch was 10 mm × 10 mm and the upper substrate was 8.5 mm × 10 mm. With an ITO contact area of 1 mm × 1.4 mm, we assembled the quadrupler such that the smaller substrate of the polarization switch faced out and the conductive spring could be pressed directly onto the ITO.

A photograph of the resolution quadrupler connector module is shown in Fig. 6, along with a U.S. dime. It was made of black Delrin. For large-volume manufacturing, it could be molded with plastics. The edge thickness of the connector is 0.8 mm, which is less than the total thickness of the glass substrate plus the linear polarizer. In this way, the quadrupler is assembled directly on top of the image source with UV epoxy. The resulting resolution quadrupler is compact and low in cost.

Fig. 6. Photograph of the compact package for a resolution quadrupler (compared with a U.S. dime).

6. Display Controller

The scanner for resolution quadrupling was tested with a VirtuoVue display. ImageScan software, a module based on ImageCreate, was used for the testing. It is a software package produced for the VirtuoVue display application development system. The basic function of this module was to allow the user to choose a bit-map file, display the image of 480 × 288 pixels, then select the alternative column and row data and send the four resulting 240 × 144 images to the integrated driver of the scanner and display.

The drive waveform and timing diagram for the video signals and polarization switches during one scanning cycle are illustrated in Fig. 7. T_S is the time allocated for the switches to settle down in the new states. T_S must be larger than T_{on} and T_{off} of the liquid-crystal switches to achieve high image quality. T_L is the time allocated for image uploading. T_F (the sum of T_S and T_L) is the time allocated per image frame. T_C is the time allocated for one scanning cycle that includes four image frames. After the final information of the first frame of the image was uploaded to the display at T_F, the bottom polarization switch was turned on immediately. After the bottom polarization switch settled to a stable state at the time $T_F + T_S$, the second frame of the image was loaded. When the information was loaded completely into the display, the top polarization switch was turned on at $2\,T_F$. After the second polarization switch had stabilized, the information of the third frame of the image was loaded at the time of $2\,T_F + T_S$, and then the top polarization switch was turned off at $3\,T_F$. Finally, the fourth frame of the image was loaded into the display at $3\,T_F + T_S$, and the bottom polarization switch was turned off at $4\,T_F$.

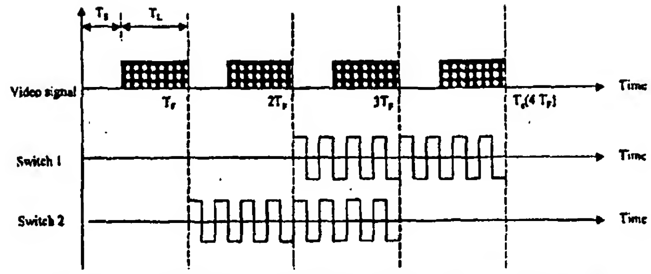


Fig. 7. Drive waveform for one scanning cycle. See text for details.

The displayed image then went back to its initial position. Each of the four images corresponded to one of the four quadrupler states, and the pixels in the image were displaced spatially 10 μm apart. The information of each image had to be completely loaded to the display before the polarization switch changed its polarization direction. And the information of each image could not be loaded until the polarization switch was settled in its stable polarization state. For the observer to perceive the integrated resolution-enhanced image, all four images must be shown within 16.6 ms ($T_C < 16.6$ ms).

We adjusted the image frame rate by adjusting the clock rate of the display. The delays between two frames could be set individually. This feature was important, as the turn-on time of a liquid-crystal switch was normally much shorter than the turn-off time. By adjusting the individual delay between two frames, we could increase the brightness and contrast of the resolution-enhanced images.

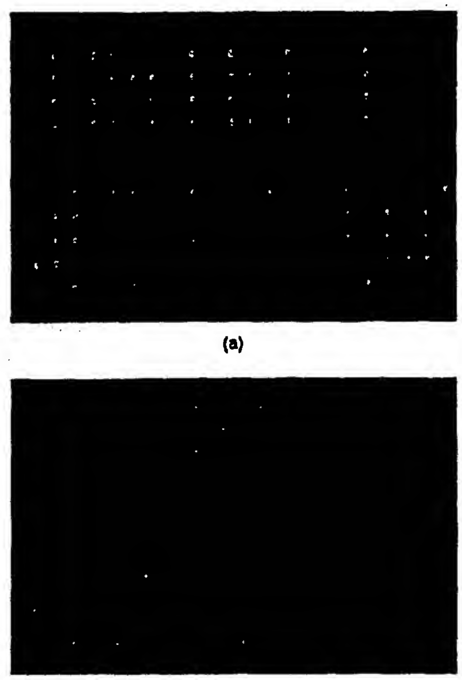
7. Display System Characteristics

The resolution quadrupler was tested with a VirtuoVue display. The VirtuoVue display image source consists of a two-dimensional array of light-emitting diodes (LED's) with 240 columns and 144 rows for a total of 34,560 pixels, which is roughly a one-eighth VGA display. The pixel pitch is 20 μm, thus the emissive area is 2.88 mm × 4.8 mm. The clear aperture of all the components in the resolution quadrupler is larger than 3 mm × 5 mm so that no pixels are blocked. The quadrupler was placed directly on top of the glass substrate of the image source and was aligned with the columns and rows of the image source under a microscope.

Starting with a one-half VGA image, we selected alternative rows and columns from the half VGA image to generate four one-eighth VGA images. The four images were stored in the memory of VirtuoVue driver as four frames of VirtuoVue images. The four frames of the image were synchronized with the polarization switches of the resolution quadrupler so that each frame was shifted by a half-pixel. The shifted distance was determined by the thickness of the birefringent crystal. The images were magnified with a microscope, and pictures were taken with a CCD camera.

The experimental results of images of a VirtuoVue display without and with a resolution quadrupler are shown in Figs. 8(a) and 8(b), respectively. Clearly the image with a resolution quadrupler provides the full information, and the image without a resolution quadrupler was illegible. For many applications such as digital cameras, e-mail, and faxes, a minimum of one-half VGA resolution is desirable if not necessary. Liquid-crystal scanners thus provide an alternative, low-cost approach for creating a high-resolution information display by use of lower-resolution image display sources.

Because the light emission across the pixel was not uniform, the fill factor appeared to be less than 25%.



(a)

(b)

Fig. 8. (a) Experimental image result without a resolution quadrupler. (b) Experimental image result with a resolution quadrupler.

for images without a resolution quadrupler, as shown in Fig. 8(a). The fill factor of images with a resolution quadrupler was improved fourfold, as shown in Fig. 8(b), but was less than 100%.

The resolution quadrupler was tested under different conditions: temperature, clock rates of the image source, driv voltages of the quadrupler, and driving methods. The resolution quadrupler and a VirtuoVue image source were placed in a temperature-controlled chamber from −20 to 60 °C. The response time of the liquid-crystal switches was a strong function of temperature. As the temperature decreased, the liquid-crystal viscosity increased, resulting in a slower response time. At room temperature, high-quality resolution quadrupled images were observed. The temperature was increased from 20 to 60 °C and then slowly decreased to −20 °C. As the temperature increased, the contrast of the images increased and the image got sharper. However, we did notice that the luminance decreased slightly at higher temperatures. Our experimental results illustrated that the transmission of the liquid-crystal scanner was approximately the same when the temperature increased. Therefore the luminance decrease was due to the fact that the quantum efficiency of the LED image array decreased as the temperature increased.

Next, we began to decrease the temperature while studying its effects on the resolution-enhanced images. The image quality remained good until the temperature decreased to 0 °C, then the resolution-enhanced image started to lose contrast and appeared blurred. The response time of the polarization switches was so slow that before the bottom polarization switch was completely turned on and settled in a stable polarization state, the second image was loaded to the display, which resulted in the second frame of the image being displaced less than 10 μm from the first frame of the image. Thus the information of the first and second images were blended together. The same situation applied to the third and fourth frames of the image. Because the loading of the four images must be completed within 16.6 ms, the amount of time for the display controller to load each image had to be reduced for slower switches.

We solved this problem by increasing the clock rate of the display so that more blanking time was left for the polarization switch to respond. We found that, with this technique, even under −20 °C, the image quality was fairly good. The display luminance decreased when we increased the clock rate, as shown in Fig. 9. However, the quantum efficiency of the LED array increased with the decreased temperature. Thus the two effects compensated each other to some extent.

The image quality of the resolution-enhanced image was excellent when the two polarization switches were biased with zero voltage for one state and ±10 V for the other state, even though the contrast ratio was low at zero bias. Because of the low power consumption requirement of portable products, a low bias voltage was preferred. We decreased the bias voltage from ±10 V all the way to zero. The image quality started decreasing but remained good until the bias voltage reached approximately ±5 V, at which point the images started looking smeared.

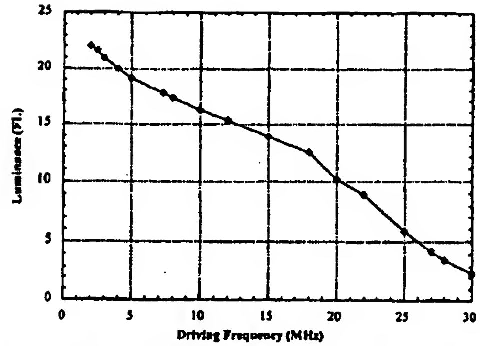


Fig. 9. Measured luminance of a VirtuoVue display as a function of clock frequency.

The alignment tolerance for the resolution quadrupler to the image array was not tight. Because the image displacer produced only relative displacement of the image source, we had no horizontal or vertical alignment issues as long as the clear aperture of the quadrupler covered the whole area of the image array. The most important tolerance needed for consideration was the angular tolerance. We found that the quality of resolution-enhanced images had almost no degradation within an alignment tolerance of ±10°. Because it was symmetric for the x and y directions, the largest angular misalignment was 45°. We found that even at 45°, the image quality still looked better than that without a resolution quadrupler.

8. Summary

We have developed a low-cost and effective pixel and fill-factor enhancement technique. This technique was tested on a VirtuoVue display and achieved a factor of 4 increase in perceived pixel count, from one-eighth VGA to one-half VGA, and a factor of 4 increase in the fill factor. This was accomplished without an increase in the number of pixels in the array, which would result in a larger chip size and subsequent higher costs. In this paper we have discussed the design of a virtual display system with a resolution quadrupler and demonstrated significant enhanced image results.

The construction of a display system involves efforts from many people across many areas of expertise. The author acknowledges management support from Philip Wright and valuable contributions from many colleagues including R. T. Huang, Karen Jachimowicz, Fred Richard, etc. at Motorola Labs and Motorola Semiconductor Product Sector.

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